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**EYE AND HEAD RESPONSE AS INDICATORS
OF ATTENTION CUE EFFECTIVENESS (U)**

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The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Kenneth R. Bell

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This study examined whether eye and head responses can be used to evaluate attention cue effectiveness. The subjects' tasks were to complete a centrally-located tracking task while periodically responding to cues to identify targets at four peripheral locations. Five directional cues were evaluated: visual symbol, coded sound, speech cue, three-dimensional (3-D) sound and 3-D speech (the 3-D cues appeared to emanate from the peripheral locations). The results showed significant performance differences in eye and head reaction time, as well as peripheral target task completion time, as a function of cue modality. Since these relatively nonobtrusive measures were as sensitive to cue modality as the peripheral task completion time, these results suggest that eye and head reaction time can be used in evaluations addressing the effectiveness of attention cues.

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EYE AND HEAD RESPONSE AS INDICATORS OF ATTENTION CUE EFFECTIVENESS

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This study examined whether eye and head responses can be used to evaluate attention cue effectiveness. The subjects' tasks were to complete a centrally-located tracking task while periodically responding to cues to identify targets at four peripheral locations. Five directional cues were evaluated: visual symbol, coded sound, speech cue, three dimensional (3-D) sound and 3-D speech (the 3-D cues appeared to emanate from the peripheral locations). The results showed significant performance differences in eye and head reaction time, as well as peripheral target task completion time, as a function of cue modality. Since these relatively nonobtrusive measures were as sensitive to cue modality as the peripheral task completion time, these results suggest that eye and head reaction time can be used in evaluations addressing the effectiveness of attention cues.

As a result of significant developments in the application of digital computers to crew system design, more information is available to aircrew members. This has resulted in an overabundance of warning lights and sounds which may tax the pilot's ability to perceive, interpret, and react to the information. Unfortunately, past approaches to designing attention cueing systems have not recognized performance limitations in a concurrent task environment. Rather, most are based solely on performance data, such as manual reaction time, collected when the operator was attending to only one task. Consequently, only limited data is available pertaining to attention cues for an operator performing multiple tasks.

Since most information displayed in aircrew systems is through the visual channel, measures of eye and head movement may be indicative of the effectiveness of candidate cues in directing attention to a particular display or control. Yet, for the most part, eye and head responses have not been examined in past attention studies. However, recent technological advances enabling accurate and simultaneous recording of eye and head movements have renewed interest in studying eye/head dynamics. The use of eye and head responses as dependent variables during visual refixations may facilitate data recording under multiple task conditions. Moreover, eye and head movement characteristics may provide an objective and relatively unobtrusive means of evaluating the effectiveness of candidate cues in attention system design.

PURPOSE

The present experiment investigated whether eye and head reaction time can be used to evaluate the effectiveness of five methods of presenting cues. Each cue directed the subjects' attention away from a central tracking task to one of four peripheral locations. Two methods involved three dimensional (3-D) auditory signals: 1)

localized sound - white noise appearing to emanate from the corresponding peripheral location; and 2) speech - either the word "LEFT", "RIGHT", "UP", or "DOWN" appearing to emanate from the corresponding peripheral location. The three remaining methods presented non-localized cues: 3) speech - same words ("LEFT", etc.); 4) visual - bar appearing either on the right, left, top or bottom of the tracking monitor; and 5) coded sound - aural signals consisting of four distinct (amplitude and phase) sinusoidal waves, each coded to represent one of the locations. Performance on the peripheral target acquisition task and the concurrent central task were also recorded in order to compare the effectiveness of eye/head reaction time measures to alternative measures.

METHOD

Apparatus

The research was conducted on the Helmet-Mounted Oculometer Facility (HMOF) residing at the Human Engineering Division of the USAF Armstrong Aerospace Medical Research Laboratory (AAMRL). (For an illustration of the overall facility configuration, see Calhoun, Janson, and Valencia, 1988.) The key components of the facility pertinent to this study are briefly described below.

Eye and head movement recording systems. The movement of the eye with respect to the head was measured with an infrared corneal "bright-pupil" reflection system (Honeywell Helmet Mounted Oculometer). A Honeywell magnetic Helmet Mounted Sight provided helmet position and attitude determination. (See Calhoun, Arbak, and Boff, 1984.)

Auditory Localizer. The 3-D aural cues were generated with a Gehring AL-100 (see Valencia and Calhoun, 1989). This electro-mechanical auditory localizer employs a single speaker positioned in front of a gimbal-mounted manikin head to provide real-time

localization of audio signals.

Simulator. The single-place cockpit simulator was surrounded by a black curtain. Five monochrome monitors were used: one X-Y monitor (12 x 10 cm) centrally located at a viewing distance of 72 cm, and four (19 x 14 cm) peripheral monitors positioned such that the 4 mm high letter targets were displaced ± 40 degrees vertically and ± 60 degrees horizontally from the forward line-of-sight, all subtending a visual angle of 0.24 degrees (Figure 1). The average luminance of the symbology was 0.54 nits. Both a voice-activated switch and headphones (for auditory cues) were connected to the helmet. A force stick was located on the right console.

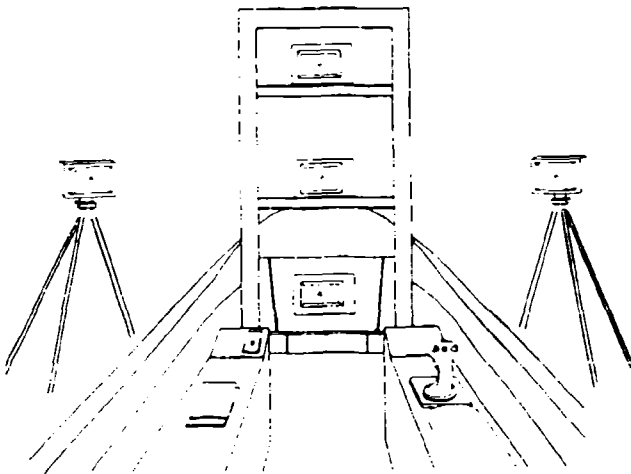


Figure 1. Illustration of the simulator.

Computer/Software Support. Eye angle data and helmet rotation/position data were sampled at a 60 Hz rate and processed by a Data General Eclipse S/130 computer. Root-mean-squared (RMS) error noise was 0.45 degrees or less at most eye positions. These data were sent, via a Network Systems Hyperchannel Adapter, to a MicroVAX II. The MicroVAX was used to record eye/head parameters and performance, as well as control the presentation of cues and present the tracking symbology and letter targets.

Subjects

Subjects were ten paid members of a contractor-maintained pool (four males and six females, mean age 23.3 years). The subjects' vision or corrected vision was 20/20. The hearing thresholds for all subjects were well within the 1984 ANSI American Standard for Audiometric Testing.

Subjects' Tasks

A dual-task paradigm was employed in which

subjects completed a manual pursuit tracking task on the centrally-located monitor and a Sternberg task on the peripherally-located monitors. A payoff matrix was used to help equate the allocation of attention between the two tasks. If performance on both tasks improved from the previous day's performance, a monetary bonus was awarded.

Tracking task. The subject's task was to maintain a dot on top of a cross hair by exerting pressure on the force stick. Performance was based on the distance between the dot and the cross hair. Summed sine waves served as the input forcing function. The bandwidth of the eight sinusoidal components was 0.3 Hz.

Sternberg task. During training, 5 subjects memorized a positive set consisting of one letter ("Q"), and 5 subjects memorized a positive set consisting of 5 letters ("AHQUZ"). The negative set consisted of all the alphabet letters not in the positive set. For each trial, white letters were presented simultaneously on all four peripheral monitors. The subject's task was to look at the letter in the location indicated by the preceding cue, determine if it was a member of the positive or negative set, and make a verbal response ("ALPHA" or "BRAVO", the particular response associated with the memory sets was counterbalanced between the 2 groups of subjects). A voice activated switch mechanism recorded the response time. The accuracy of the response was recorded manually. After the verbal response (or if four seconds had elapsed), the letters disappeared and the subject returned to the tracking task.

Procedures

In each run, and while the subject was tracking, one of the five cues was presented 16 times (four times to each peripheral monitor). The interstimulus interval between cue and target presentation was 350 milliseconds (ms). A variable intertrial time period of 7-14 seconds was used.

Eight five-minute runs constituted a session. Each subject completed 24 runs across 3 consecutive sessions with each of the 5 cues for a total of 15 test days. Data from the final 4 runs per cue were analyzed (3200 trials: 16 trials x 4 runs x 5 cue conditions x 10 subjects). The dependent variables were: reaction time of the eye and head (time from cue onset until the eye/head moved at least 1.5 degrees towards the appropriate target for 50 ms), Sternberg task accuracy, Sternberg completion time (time from cue onset until the verbal response), and tracking performance in terms of RMS error.

Experimental Design

The effects of cue and target location were evaluated using a within-subjects design. Each subject was randomly assigned a sequence of the five cue conditions. The sequences were determined by use of a balanced Latin square such that, across subjects, each cue was preceded equally often by each of the other cue conditions. The order of the four target locations (left, right, up and down) were randomly assigned during each run with the constraint that a target was presented four times in each location. For the four trials in each location, a positive set target was presented in two trials and a negative set target in two trials.

Data Analyses

These data were screened to delete trials in which the Sternberg task was completed incorrectly, and trials in which the eye/head were either not tracked by the system or were not directed towards the central tracking monitor at the start of the trial (2.47% and 10% of the trials, respectively). For the remaining 2801 trials, eye and head reaction time, tracking RMS error, and Sternberg task completion time were determined for each subject for each of the cues and target locations. Mean performance across the final block of 4 runs for each of the dependent variables was submitted to an analysis of variance (ANOVA). Since positive set size was found to have no significant main or interaction effects, this variable was dropped and the analyses rerun. Both square root and natural log transformations were performed on the reaction time data. Since these results did not differ from those obtained with the raw data, the nontransformed data are represented herein. In those cases where the ANOVA revealed significant effects, a test of the least significant difference ($\alpha = 0.05$) was conducted.

RESULTS

The results pertaining to mean eye and head reaction time showed significant differences between all the cues, except for eye reaction time with the two speech cues (eye: $F(4,36) = 37.66$, $p = 0.0001$ and head: $F(4,36) = 48.02$, $p = 0.0001$; see Figure 2).

The means for eye and head reaction time showed similar trends across the four target locations and can be ordered, from fastest to slowest, as follows: right, left, up, and down. While these differences were not significant for the eye ($F(3,27) = 1.48$, $p = 0.2414$), there was a significant effect of target location on head reaction time ($F(3,27) = 5.38$, $p = 0.0049$). This effect, however,

should be interpreted in light of the significant interaction between target location and cue ($F(12,104) = 5.56$, $p = 0.0001$; Figure 3). (A similar interaction with eye reaction time was not present, $p = 0.4362$.) Subsequent analyses of the performance with each cue as a function of target location (LSD = 0.126; $p < 0.05$) showed that the coded sound consistently resulted in the slowest head reaction times across all four locations. However, head reaction times following the visual bar were faster than times with the 3-D speech, speech, and coded

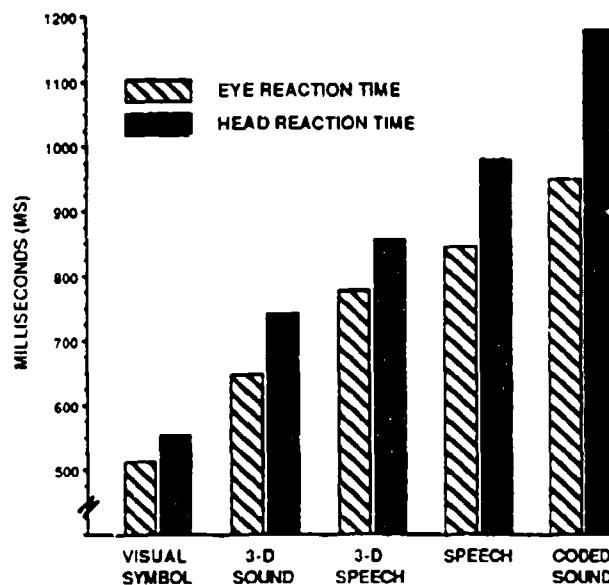


Figure 2. Mean eye and head reaction time with each cue.

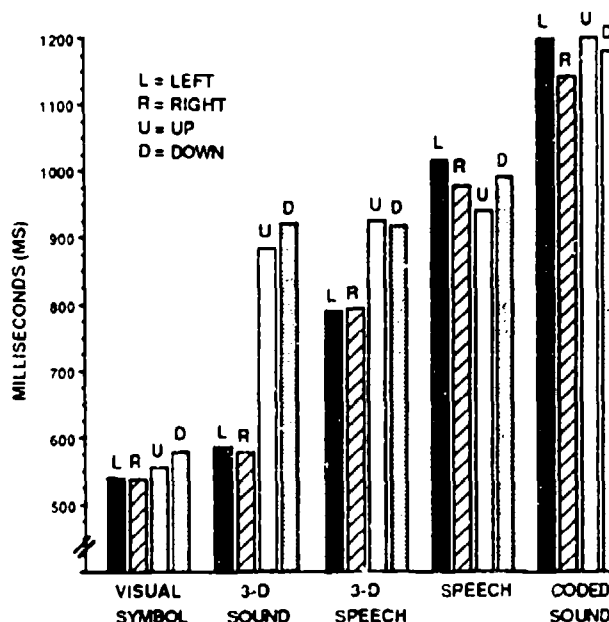


Figure 3. Mean head reaction time with each cue as a function of target location.

sound for all four locations. The head reaction time following the visual bar was also significantly faster than that following the 3-D sound condition for the up and down locations, but not for the left and right locations. Finally, for the left and right locations, head reaction times with the 3-D sound were significantly faster than times with the two speech cues (besides the coded sound).

The analyses regarding the differences in head reaction time between target locations within each cue ($LSD = 0.107$, $p < 0.05$) showed no significant differences as a function of target location for the visual symbol, coded sound, or speech cue conditions. For both localized conditions (3-D sound and speech), reaction times were significantly longer for the up and down locations, but not for the right and left locations.

The results of an earlier analysis of the Sternberg task completion time are consistent with the differences found here in the eye and head reaction time as a function of cue. The Sternberg task completion time results are also similar to the head reaction time results in terms of the differences between cue conditions as a function of target location. Further details pertaining to the analyses of Sternberg task completion time are available in Calhoun et al. (1988).

The results of the ANOVA examining tracking performance showed no significant difference as a function of cue ($F(4,36) = 0.22$, $p = 0.9254$). The mean RMS error across cue conditions was 0.67 inches.

DISCUSSION

The key finding from the analyses was that the results for eye and head reaction time were similar to the results presented earlier pertaining to Sternberg task completion time (Calhoun et al., 1988). Since these nonobtrusive measures were as sensitive to the cues as the conventional response time measure, these results suggest that experimenters have the option of not using a paradigm which forces an operator to make a response after a cue.

Since the results for eye and head reaction time are so similar to the Sternberg task completion time results, the findings pertaining to performance differences between cue conditions will not be discussed herein (see Calhoun et al., 1988). Note, in comparing Figure 3 from the present paper to Figure 3 in the earlier paper, that although the key results are similar, for some cues, the trends for the left/right locations and up/down locations show slight differences between Sternberg task completion time and

head reaction time. These small differences can be attributed to the increased variability of the head reaction time data. Even though the present paper does not specifically address the results pertaining to each cue, discussion will be provided regarding overall performance between the visual and 3-D auditory sound cues, in order to compare the present results with earlier studies examining such responses.

Past studies have shown significantly shorter latencies in eye/head movements elicited by auditory rather than by visual cues. This was the case in a study by Whittington, Hepp-Reymond, and Flood (1981) which examined monkey auditory and visually triggered movements (mean differences were 56 and 59 ms for eye and head, respectively). These authors attributed the quicker auditory response times to delay differences in the transduction mechanism between the two modalities: whereas, activity in the primary auditory afferent follows an auditory stimulus by less than 2 ms, a delay of approximately 20 - 100 ms can occur between the time light strikes the retina and the onset of activity in the retinal ganglion cells.

Zambarbieri, Schmid, Magenes, and Prablanc (1982) also found that horizontal eye movements with humans averaged 40 ms shorter with auditory targets, compared to visual targets, in a task measuring simple reaction time to eccentric targets. However, when the subjects were tasked to not only respond when they detected a target, but to also fixate the target as accurately as possible, the opposite was found - reaction time to the visual targets was shorter than that to the auditory targets (an average difference of 70 ms). Similar results were found by Engelken and Stevens (1989) in a paradigm employing a single moving visual target and a constant-intensity moving auditory target. In the present study, mean eye reaction time (across locations) was similarly longer (135 ms) with the 3-D sound, compared to the visual bar. However, further examination of the data showed that this large difference was mainly due to performance with the up and down target locations. The difference between the 3-D sound and visual bar was 186 ms for the up and down locations, but only 84 ms for the right and left locations. Likewise, it was observed in Zambarbieri's study that performance was poorer when sounds were presented near the median sagittal plane where the temporal and amplitude differences between the two signals reaching the two ears is quite small.

These results support the suggestion made by Zambarbieri et al. (1982) that one reason the "auditory saccades" were slower than the "visual saccades" in paradigms involving

central processing is that the uncertainty associated with auditory spatial information is not only greater than that affecting visual spatial information, but it is also dependant on stimulus position with respect to the head. Thus, the longer time needed for processing auditory spatial information would reverse the relationship observed between simple reaction times for auditory and visual responses. These data suggest that only the processing time is different between the visual and auditory targets, not the final accuracy of the saccadic auditory response. However, any potential delay in responding to auditory cues which may impact the pilot's ability to perform time critical tasks needs further investigation.

Although the above discussion has centered on eye latency, the conclusions are pertinent to head movements as well, since the motor strategy in coordinated movements to targets involves both eye and head movement. Thus, the head reaction time data showed similar trends to the eye reaction time data. Note, however, only head reaction time in the present study, not eye reaction time, significantly differed between cue conditions as a function of location. Such results may reflect differences in head movement strategies among the subjects. Further investigation comparing the utility of eye and head movement measures for use in the design of attention cueing systems is needed.

CONCLUSIONS

This study showed that eye and head reaction time can serve as objective indicators of the effectiveness of candidate attention cues. Since these nonobtrusive measures were as sensitive to cue modality as Sternberg task completion time, the results suggest that such measures are not only valuable in the design of attention cueing systems, but also in overall cockpit design since they may enable the detection of a pilot's awareness of rapid changes in information presentation (e.g., rapid sequence of cues in a simulated engine failure or format changes on a multifunction display). Moreover, measurement of eye and head response can be accomplished without requiring the pilot to make a separate response in addition to traditional piloting tasks.

The results of this study also provide pertinent data on the effectiveness of candidate cue modalities. Of special interest is the fact that eye and head reaction times with the 3-D sound cue, for the left and right locations, were on the average only 84 and 42 ms, respectively, longer than that with the visual cue. Such results indicate that 3-D

auditory signals can be effectively used as directional cues. However, the results for the up and down locations illustrate that further investigation is required on characterizing auditory cue effectiveness as a function of stimulus location. In order that additional processing delays are not imposed on the already time intensive tasks to be performed by tomorrow's pilots, it may be necessary to limit the application of 3-D cues to those locations where pilots have little uncertainty associated with the auditory spatial information. It is also possible that training procedures can be developed to minimize any processing delay imposed by auditory spatial information uncertainties.

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